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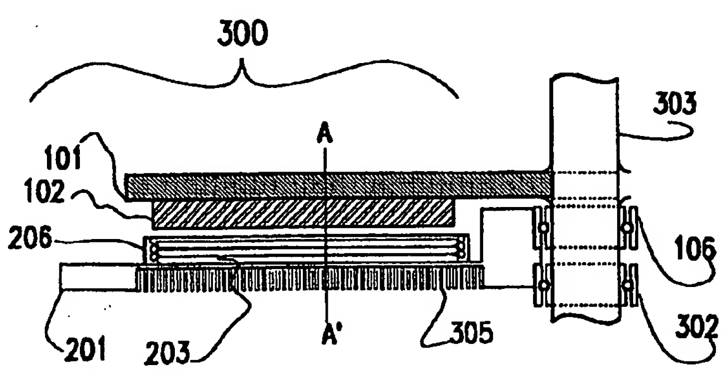

(57) Abstract

A disk shaped brushless direct current electric motor has a plastic stator disk (201) and a plastic rotor disk. The plastic stator disk (201) has an annular cavity on one face retaining a spiral coil (305) of thin lamination steel and a plurality of radial fingers on the opposite face to support conductive windings (206). The plastic rotor disk contains and supports a backing plate of mild steel (101) attached to a central shaft (303). An annular ring magnet (102) is attached to the steel backing plate. The annular ring magnet has from 4 to 24 permanent magnetic poles; preferably eight poles.

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PLASTIC BRUSHLESS DIRECT CURRENT DISK-SHAPED ELECTRIC MOTOR

TECHNICAL FIELD OF THE INVENTION

This invention relates to the field of dynamo-electric machines; particularly brushless direct-current electric motors (BDCMs) and more particularly to those BDCMs constructed in the disk-shaped style.

BACKGROUND

Advantages of the BDCM (brushless direct current motor) type of dynamo-electric machine (motor or generator) over prior-art slotted armature motors include:
no commutator - no sliding contacts carrying significant current,
absence of cogging - no repeating iron structures to preferentially attract magnetic poles,
lighter weight, (no laminated iron structures),
simpler construction, there being a possibility for greater clearances, and
higher efficiency (for example, less inductance in the windings).

Most BDCMs are constructed in a pattern involving adjacent (ie side by side) cylindrical surfaces between which the interaction of magnetic forces operating in a radial direction provides a torque. Some motors are constructed in the disk style rather than as cylindrical, relatively elongated motors, because a disk style is useful for a number of particular applications. Disk motors employing brushless direct current drives instead of segmented copper commutators are known. In these motors, a few separate magnets are typically attached to a mild steel yoke and an armature is sandwiched between the magnets and a second mild steel yoke.

There is a need for an improved, efficient economical motor having a flattened, disk-shaped shape.

OBJECT

It is an object of the present invention to provide an improved disk-shaped electric motor, or one which will at least provide the public with a useful choice.

STATEMENT OF THE INVENTION

In a first broad aspect the invention provides a disk shaped brushless direct current electric motor comprising a disk-shaped stator and disk-shaped rotor positioned so that the rotor can rotate in a plane substantially parallel to the plane of the stator with a gap therebetween, a plurality of permanent magnetic poles supported on or in a surface of the disk-shaped rotor facing the stator, said stator having a plurality of wound poles supported by said stator wherein the stator disk is formed of a plastics material and the rotor disk is formed of a plastics material; the plastic stator disk having a first face retaining an annulus formed from one or more portions of soft magnetic material which is electrically discontinuous, the plastic stator disk facing conductive windings or near a second face; the plastic rotor disk contains and supports a backing plate of soft magnetic material and the plurality of permanent magnetic poles supported thereon or therein face the conductive windings of the stator disk, such that magnetic flux paths from one permanent magnetic pole to an adjacent magnetic pole extend in a region intersected by conductive windings and into said annulus of soft magnetic material and back across said region to said adjacent permanent magnetic pole.

In a second broad aspect the invention provides a disk shaped brushless direct current electric motor having a disk-shaped stator and a disk-shaped rotor mounted on a central shaft so that the rotor can be positioned close to and rotate in a plane parallel to that of the stator with a gap therebetween, a plurality of permanent magnetic poles supported on or in a surface of the disk-shaped rotor facing the stator, said stator having a plurality of wound poles supported by said stator wherein the stator disk is formed of plastic and the rotor disk is formed of plastic, the plastic stator disk having an annular cavity on a first face retaining an annulus formed from one or more portions of soft magnetic material which is electrically discontinuous, the plastic stator disk having on a second face a plurality of radial fingers supporting conductive windings, the plastic rotor disk contains and supports a backing plate of soft magnetic material and has an annular ring magnet supported on and attached to said backing plate so that the ring magnet faces that portion of the stator having the conductive windings, the annular ring magnet having from 4 to 64 permanent magnetic poles magnetized in zones around the

annular ring magnet, such that magnetic flux paths from one permanent magnetic pole to an adjacent permanent magnetic pole extends across a region intersected by conductive windings and substantially into said annulus of soft magnetic material, then returns back across said region to said adjacent permanent magnetic pole, whereby a majority of said conductive windings intersect substantially all of the magnetic flux paths substantially at right angles.

Other features of the invention will become apparent from the claims and the description of this invention.

DRAWINGS

These and other aspects of this invention, which should be considered in all its novel aspects, will become apparent from the following description, which is given by way of example only, with reference to the accompanying drawings, in which:

Figure 1: is an illustration of the face of a first rotor for a preferred disk motor, and also shows a ring magnet for such a motor.

Figure 2: is an illustration of the face of a stator for use with the rotor of figure 1, including a winding. The disposition of the magnetic poles has been superimposed.

Figure 3: is a sectional view on a radius through the rotor and stator of a motor of the present invention.

Figure 4: is a sectional view along the plane A-A' of Fig 3; including the magnet array, showing flux lines, and windings on the stator, and the rotor of a motor in accordance with the invention.

Figure 5: shows a prior-art situation for comparison with Fig 4, where no annulus behind the windings exists and the flux lines are not "dragged through" the windings by the magnetically permeable annulus.

Figure 6: shows details of the plastic former used in the stator of the 8-pole, three-phase motor. Dimensions are in inches.

Figure 7: is a diagram showing the plastic moldings used in the 8-pole, three-phase motor.

Figure 8: is a cross section through the plastic former of the stator for the 8-pole, three-phase motor - this molding is both a coil former and a holder for the annulus. Dimensions are in inches.

The preferred version of this invention comprises a disk shaped brushless direct current electric motor having a disk-shaped stator 200 and a disk-shaped rotor 100, mounted on a central shaft. Both the stator disk and the rotor disk are formed of plastic; the plastic stator disk having an annular cavity on a first face retaining an annulus formed from one or more portions of soft magnetic material which is electrically discontinuous. On its second face the plastic stator disk of this invention also includes a plurality of radial fingers capable of supporting conductive windings - typically of enameled copper wire.

By "electrically discontinuous" we mean that the magnetic material that comprises the annulus is effectively incapable of carrying a bulk electric current (eddy current) generated by the moving magnetic poles. One example of such a discontinuous material is a soft ferrite; another example, which is preferred, is a spirally and reasonably tightly wound length of steel tape made of transformer lamination steel. We have found that it is not necessary to coat the tape with an insulating material to prevent current flow cutting straight across the gap between adjacent turns, because natural oxide coating seems to be sufficient insulation at the low voltages developed between adjacent turns, although in some cases an insulating coating may be desirable.

A mass of steel tape or wire wound in this organized way is an anisotropic electrical conductor - by which we mean that it can conduct well in one axis or in one plane, and it is preferable to orient that axis in a direction substantially perpendicular to that of the flux and to that of the windings.

The plastic rotor disk (101 in Fig 1) contains and supports a backing plate of soft magnetic material. An annular ring magnet (102A in Fig 1) is supported on and attached to said backing plate so that one face of the ring magnet faces that portion of the stator having the conductive windings. The annular ring magnet has from 4 to 64 permanent magnetic poles magnetized in zones around the annular ring magnet, although the preferred version has 8 poles; four North (N) and four South (S) poles.

Magnetic flux paths following a magnetic circuit from one permanent magnetic pole to an adjacent permanent magnetic pole extend through a region intersected by conductive windings and into said annulus of soft magnetic material (preferably steel tape) and back across the region to the adjacent permanent magnetic pole, and a feature of this design is that a majority of the conductive windings intersect substantially all of

the magnetic flux paths substantially at right angles. Fig 4 shows the paths, such as 408.

The embodiment to be described refers to a brushless direct current motor (BDCM) in which a torque is developed across a plane surface between a rotating permanent magnet and a fixed array of energized windings. The motor comprises two disks in a stack, one - a stator 201 fixed to mountings (not illustrated) and the other - a rotor 101 capable of rotation about its center on a shaft 303, which is preferably mounted on bearings 106, 302. Generally there will be an array of conductive windings (in this case wound from copper wire), generally in sets of three (202, 203, 204) placed on one face of the stator/fixed disk, and an array of permanent magnetic poles (such as 103, 104) is created with specifically magnetized zones on the annular ring magnet on one face of the rotor. This fixed winding arrangement avoids the need for wiping contacts to transfer electricity. We prefer to use a three-phase driving scheme for this BDCM for the sake of simplicity and low cost, although more or fewer phases could be used.

RING MAGNET

An annular ring magnet made of a magnetically hard ferromagnetic substance is supported on and attached to a mild steel backing plate in said rotor so that the ring magnet faces that portion of the stator having the conductive windings. "Ceramic 8" material is one preferred magnet composition. Although this preferred-embodiment low-cost disc BDCM motor has 8 poles (see Fig 1) the number of poles may range from 4 to 64. For example even more than 20 poles may be preferred in the event that this motor is constructed with a wider diameter, such as for an optimized low-RPM fan for use in air conditioning.

Permanent magnetic poles are magnetized in zones around the face of the annular ring magnet. The poles are aligned so that the flux emerges substantially parallel to the axis of rotation of the motor. Each pole of the ferrite magnet is shaped in the form of a truncated sector of a circle, as shown (103, 104) in Fig 1, having an angle of typically 45 degrees between its sloping sides in the case of an 8-pole motor. Other angles between poles will be preferred for other numbers of poles, generally being at 360/number of poles degrees apart. The example magnet is 114 mm OD, 56 mm ID, and 10 mm thick. A balancing mass may be placed about its inner diameter 105. Preferably the ferrite magnet is magnetized so that substantially the entire exposed surface of a mounted magnet is either a North or a South pole, as shown for the 8-pole

magnet in Fig 1.

Magnetizing a ring magnet inevitably leaves a small amount of inactive "border" material midway between pole centers. It is helpful if the amount of this material is minimised because if the poles are in effect closely spaced then the majority of the lines of force are forced away from the magnet and outward towards the intended position of the windings, so that the motor efficiency is enhanced. If the lines of force are oriented sideways and over the magnet surface, they may never intersect the windings. A high number of poles tends to raise the relative amount of border material. The prior art example 500 in Fig 5 shows how lines of force could in a sub-optimal design return to another pole on the surface of the ring magnet without ever intersecting the area 502 occupied by the windings 203 of the motor.

Preferably, the rotor molding includes a circumferential lip to retain the magnet which lies against a substantially flat plate of mild steel 101 which serves to complete the magnetic circuit between one pole and its neighbors (as shown in Fig 4). Optionally the plate of mild steel - rather than the plastic molding - may be provided with a turned rim to help prevent the magnet from being displaced by centripetal forces. Optionally, adhesive attachment means is used to hold the ring magnet onto the steel plate. Preferably the plate of mild steel is firmly attached to the rotatable drive shaft 303 of the motor. It will be appreciated that during rotation the plate and the magnet together may have a significant amount of angular momentum. Preferably the attachment means will be capable of retaining the ring magnet in position even under overload conditions at an elevated temperature.

An example preferred air gap between the rotor and the stator is 1 mm ± 0.2 mm. This is significantly greater than the usual air gap to be found in an induction motor, and provides more tolerance during manufacture and allows for play, or wear. Optionally this air gap may be alterable by a particular arrangement of bearings 106, 302 which would perhaps become a sleeve bearing or roller bearings that allow the rotor and stator to be separated by a variable amount along an axial direction. Increasing the air gap which is then feasible even during a cycle of operation has the effect of decreasing the coupling of the motor.

STATOR

The molded plastic stator of our motor serves three purposes. See Fig 8 (800) for a sectional drawing through the stator, and fig 6 for a view of a portion 600 of the preferred winding supports 601 and sensor mounts 603, 604, 605. Firstly it supports the windings with fingers 803 - 804 and thereby acts as a coil former, preferably with minimal distortion during operation when the reaction torque developed by the current against the magnetic flux is produced within the windings. The windings are supported on one stator face - the face placed nearer to the rotor magnet. Secondly it supports, on its opposite face at 801 , 709, the annulus 702 (Fig 7) of soft, low-loss magnetic material that pulls the flux through the windings (see "Magnetic Circuit" below). The stator itself is supported onto a framework by screws inserted into holes 805. Thirdly, it determines the distance between the windings and the annulus, helping to define the motor's characteristics. The stator 201 is preferably composed of a rigid, non-conducting material.

The preferred stator is a plastic molding having an open construction allowing an automatic or manual winding operation to thread the preferred three separate windings radially and then circumferentially around the stator until enough turns have been placed for the winding impedance. Windings traverse radii at separations of about 45 degrees for an 8-pole motor. Alternatively the windings may be laid down as printed-circuit strips, or stamped out, or they may be potted in an embedding material. Fig 2 shows three phases 203 (heavy line), 204 (dashed line) and 202 (thin line) in place each as a single turn around the stator.

Figs 3 and 4 show potting material as 206, embedding or covering the windings "potted windings". The windings can be potted in a substantially rigid matrix of a flame-retardant plastics material (as 304), such as an epoxy, a polyurethane, or a silicone rubber. Generally it is more convenient for manufacturing and for heat dissipation purposes to wind the wires over the outside of a substantially rigid former. Any one of a number of commercial products (e.g. "RYNITE" (a trade mark of Du Pont)) designed for electric appliances and with at least some durability under high temperature may be selected as a material for a former. Windings may be attached to this surface by (for example) adhesives, embedment in grooves, or windings may be wrapped around a type of coil former (see figs 6 and 7).

Preferably the material of the former has a low magnetic permeability, less than 20 relative to air (where air is taken as permeability = 1), and is thick enough to at least partially separate the fields generated by the windings from any nearby conducting or ferromagnetic substances in order to (a) minimise losses due to hysteresis and eddy currents, and (b) minimise losses due to unnecessarily high winding inductance. (One particular advantage of BDCMs of this design is that they have a relatively low winding inductance and hence can be drive at higher frequencies).

MAGNETIC CIRCUIT

A preferred option for this type of motor is the use of an attracting layer or backing, behind the windings, of a soft ferromagnetic material which serves to attract or direct more of the lines of flux in a more perpendicular direction, through the windings without at the same time having a significant adverse effect on the inductance of the windings. This attracting layer is also referred to herein as an annulus.

The torque (Nm/Ampere) is increased by about 70%. The inductance is approximately doubled over that of a totally ironless motor, and in one example is about 320 microhenries per winding. (By way of contrast, the windings of a conventional iron motor, which are laid in sectors in an armature, behave as iron-cored inductors and hence have high inductances -perhaps ten or more times that of the example).

Figs 4 and 5 are tangential sections through a disk motor, while Fig 3 is a radial section. Note that the annulus of the radially sectioned motor 300 in Fig 3 is shown as narrow boxes, because this section has cut across the multi-turn spiral of tape, while in Fig 4 the layer 305 is shown as wide boxes, for this section has been cut approximately along the lengths of tape.

In Fig 4, we have attempted to indicate the probable directions of lines of flux in an example (400) with an attracting layer, and have provided a prior art example (Fig 5) without an attracting layer. Note that the parallelogram labelled A, A' in Fig 4 represents the plane taken from the line A, A' of Fig 3. The attracting layer 305 tends to draw out the lines of flux 408 emerging from the magnet poles (such as 103 or 104) further into, and through the windings 202, 203, 204 which may be embedded in (or at least held by) a low-permeability matrix. The three separate windings of the preferred version are shown as thin lines (202), thick lines (203), and dotted lines (204). Close

consideration of the angles between the flux lines and adjacent sectioned windings within the area 502 (in the prior-art example of Fig 5 which lacks an attracting layer) will reveal that many of the lines of flux are curving as they pass through the zone of the windings (if they reach the windings at all). The resulting torques form angles to the preferred direction of rotation. This is clearly a less effective motor than the version of Fig 4 including an attracting layer, where the flux lines are more perpendicular to the direction of rotation.

The attracting layer will experience and contain travelling magnetic fields from each of the many magnetic pole pairs of the rotor as a consequence of attracting more flux from the magnet poles and directing the flux through the windings and through itself. Therefore, a preferred attracting layer will have magnetic properties that include: low risk of saturation in use, low hysteresis loss, and low eddy currents (known as Foucalt currents in some countries). Various "soft" magnetic materials that satisfy these properties are known.

A soft ferrite may be suitable, but the permeability is not as good as the next option, and the cost is significant.

One preferred attracting layer is shown as 305 in Fig 3. This represents a section through a tight spiral made of steel tape wound on itself outwards from near the center of the stator (like the turns of tape in an audio tape cassette). A preferred steel is transformer iron lamination, which may include a thin insulating layer. Spirals can be made automatically by a simple winding operation. The stator molding may be made to include a recess for this spiral so that it is accommodated as a press fit and is held at a controlled distance from the windings of the motor.

Optionally many turns of iron wire may be wound so as to occupy a comparable space, or the ferromagnetic material is molded into the plastics matrix at the time of molding, so that it is held firmly and magnetostrictive noise is minimised. The attracting layer may alternatively form a foundation material for the stator, if it has sufficient intrinsic strength. Preferably there is sufficient ferromagnetic material present within the attracting layer to avoid saturation of the attracting layer during use.

The ferromagnetic layer 101 in, or comprising, the rotor serves to complete the magnetic circuit as shown in Fig 4, and this experiences only a substantially static magnetic field. Hence it may be less soft than the attracting layer, and mild steel is a preferred material especially as it experiences centrifugal forces during use. Optionally the flux may be "focused" or directed away from the ends of the windings where the current is flowing in a direction of no relevance to generation of a useful torque, by using an attracting layer less wide than the magnet layer. This reduces the effective length of the windings, in relation to winding inductance.

WINDINGS

An array of conductive windings 205 generally in three sets (202, 203, 204) placed on one face of the stator/fixed disk, and an array of permanent magnetic poles (such as 103, 104) is created with specifically magnetized zones on the annular ring magnet on one face of the rotor. This fixed winding arrangement avoids the need for wiping contacts to transfer electricity. We prefer to use a three-phase driving scheme for this BDCM for the sake of simplicity and low cost, although more or fewer phases could be used.

Preferably the motor windings are wound in a three-phase configuration, which may be connected together as star or delta configurations, or remain as three separate windings depending on the preferred method for energization of the windings. The windings are preferably wound in copper wire, although other fabrication techniques such as stamping from a sheet, or printed-circuit techniques may be employed. One preferred winding configuration is a rosette shape as per 203 (one turn of one phase) in Fig 2 in which the portions of any energized winding passing along a radius will generate a magnetic field capable of interaction with the flux emanating from the magnetic poles, and in which the inner and outer perimeter lines (like 206) are simply connections. A full lap winding technique (passing over each pole) is used; alternatively a half-lap winding process (over alternate poles) may be used. Assuming three electrical phases, windings of each phase are offset by (120 / pole number) degrees from the adjacent phase. In Fig 4, 202, 203 and 204 shows three groups (phases) of ingoing windings - each phase as five grouped circles representing wires in section.

A "RYNITE" molded former for winding a stator for an 8-pole motor shall now be described with reference to Figs 6, and 8. As mentioned above, the use of a former allows the coils to be wound by machine, to be immersed in air (allowing for cooling) and hence more power can be obtained than if the coils were potted and could not so easily dissipate heat arising from ohmic losses and/or eddy current losses. Furthermore less materials are used in manufacture, so the motor is cheaper and lighter.

In Fig 6 a part of the former is shown from behind - the opposite side to the air gap. The annular attracting layer is placed in the cavity 606; covering a part of each of the 24 fingers 601 of the former. The fingers act as protrusions about which the windings are wound. Wire occupies the spaces between the ribs but does not occupy the intermediate portions such as at 602. These intermediate portions may be apertures to allow the passage of a cooling fluid such as blown air. (Example dimensions in Figs 5 and 8 are in inches).

Fig 8 shows a cross-section through the complete former, along the line A---A' in the lower part of Fig 6. The former is radially symmetrical about a center axis 802. Windings are wound around the protrusions 601 (outer) to 602 (inner). The position of the attracting layer previously illustrated as 305 (which layer here comprises a spiral of iron tape) is within the space 606. The windings themselves are separated from the attracting layer by (in this example) no less than about 1.5 mm of plastic. Note that the characteristics of the completed motor (principally its inductance) are well controlled by virtue of having a substantially incompressible plastics layer of a defined thickness between the windings and the annulus. Because motor speeds of up to 30,000 revolutions per minute can be constructed it will be evident that driving current reversals at frequencies of the order of at least 4 kHz (assuming 8 poles) are feasible. The attracting layer is preferably mounted on a further disk of plastics material, to which the coil former is screwed, and that further disk includes a pair of ball bearings or the like in order to hold the rotor shaft in relation to the stator, yet allow the rotor shaft to spin freely. We refer to this further disk as a cover plate, shown as 701 in Fig 7. It provides a housing (on the far side of the illustrated aspect) for a further bearing 106 for the shaft of the motor. The cover plate includes ventilation apertures 707 and mounting holes 706. It also includes access holes 705 for some Hall-effect magnetic sensors should the BDCM drive employ such devices to sense rotation. 711 indicates some plastic protrusions for wire terminating purposes.

In order to sequence the energization of the windings, a practice which is used to create a torque, a controller having solid-state switches is preferred. Such controllers are commonly used in motor systems employing the BDCM family and are well-known to those skilled in the relevant arts, and may be synchronized to the position of rotation by Hall-effect or other magnetic sensors, optical sensors, or more preferably by sensing the back-EMF voltages generated during motion in un-energized windings. Some applications including traction applications may use magnetic sensors such as Hall-effect sensors. Three sensors are usually sufficient. Fig 6 shows slots for mounting three magnetic sensors at 603, 604, and 605. Fig 7 shows corresponding access slots in the cover plate at 705. The sensors are mounted in the shoulder section of the slots of the stator. This arrangement provides sensors at a spacing suitable for 60 electrical degree timing purposes, while sensors may be placed in alternate slots for 120 degree timing.

HOUSING

A separate housing resistant to foreign bodies is preferred, although it is conceivable that a motor of this type could be integrated into the housing of an appliance such as a clothes washing machine, because it has been found that cylindrical topographies for motors of this type (our subset of BDCMs) may be constructed with a relatively large air gap between stator and rotor, and hence the amount of play found in an operating appliance such as a washing machine may not be excessive.

FURTHER TEST DETAILS OF AN EXAMPLE MOTOR

The rotor comprises a steel backing plate, about 115 mm in diameter and on its "magnetic surface" - the surface adjacent to the copper windings - it carries a strontium-ferrite ring magnet preferably of grade 8H, imprinted with 8 poles. The magnet is 114 mm OD, 56 mm ID, and 10 mm thick, This magnet may be magnetized at the factory or in place, after adhesive mounting.

The windings are three-phase windings each of 0.63 mm insulated copper wire, 12 turns per pole, for a total of 96 turns. The line-to-line or single winding resistance is 1.8 ohms; the line-to-line inductance is 320 microhenries. A full lap winding technique is used.

The attracting layer in one example motor is comprised of a strip of silicon iron in tightly coiled watch-spring form. The strip is 5 mm wide, 0.4 mm thick, and about 30 turns of the strip comprise the attracting layer assembly. The outer diameter of a spiral is 106 mm, and the inner diameter is 75 mm. The characteristics of the magnetic field may be inferred in a pragmatic way from the above windings characteristics together with the performance details of the motor - its back-EMF (kV) is 9 volts per thousand RPM; and its torque coefficient is 0.086 Nm per A.

VARIATIONS

It is important to remember that the 8-pole, three-phase brushless DC disk motor with a ring magnet that is 114 mm (c. 4.5") outside diameter (OD), 56 mm inside diameter (ID), 10 mm thick, as described above is but one embodiment of the invention.

Motors having power ratings from 0.05 to 1 Hp torque may be constructed.

Motors having design speeds of from 40 to 30,000 revolutions per minute have been planned.

Air gaps between the rotor and the stator may be from ten to 150 thou (0.25 mm to 3.8 mm) have been included in designs.

Pole numbers from 4 to 24 poles have been used in motor designs.

Magnets may be made of other magnetically hard materials apart from the example strontium ferrite "Ceramic 8", for instance they could be made of the alloy "Alnico", or neodymium, or cobalt/samarium, or the like.

Motors having magnets of varying sizes between 2 and 10 inches OD are under consideration. A thinner lighter magnet, in which the (OD-ID)/2 thickness is 15 or 20 or 25 mm rather than the example 30 mm, is expected to be an advantage in terms of at least a reduced angular momentum. (Correspondingly, the steel backing plate may have the shape of a thick washer that underlies the magnet, rather than a substantially circular shape.

ADVANTAGES

Advantages of the disk-shaped BDCM according to this invention and including an iron backing or attractive layer within the stator include (but are not limited to):

(1) greater efficiency; better torque coefficient, there being more magnetic flux given a certain amount of permanent magnetic material, and that flux intersects the windings in a more perpendicular direction, less winding wire is required to reach a certain torque coefficient; given a certain amount of permanent magnetic material,

(2) easier construction; moulded plastics locate the magnet the annulus, the windings, the bearings, determine the winding-to-annulus spacing, because the windings are easy to wind, and because the stator and the windings have (at least in some options) a hard, metallic foundation, and

(3) better electrical characteristics; principally lower winding inductance than a motor having ferromagnetic material surrounding the windings.

INDUSTRIAL BENEFITS

Industrial benefits of this embodiment include those of optimized cheapness and efficiency, the motors being relatively easy to make owing to their open construction and low component count, and they are relatively efficient to operate.

Further variations which may be developed after reading about these embodiments may be evident to the worker skilled in the art but nevertheless will come under the scope of this invention.

Finally it will be appreciated that various other alterations or modifications may be made to the foregoing without departing from the scope of this invention as set forth.

CLAIMS

1. A disk shaped brushless direct current electric motor comprising a disk-shaped stator and disk-shaped rotor positioned so that the rotor can rotate in a plane substantially parallel to the plane of the stator with a gap therebetween, a plurality of permanent magnetic poles supported on or in a surface of the disk-shaped rotor facing the stator, said stator having a plurality of wound poles supported by said stator *characterised in that* the stator disk is formed of a plastics material and the rotor disk is formed of a plastics material; the plastic stator disk having a first face retaining an annulus formed from one or more portions of soft magnetic material which is electrically discontinuous, the plastic stator disk facing conductive windings or near a second face; the plastic rotor disk contains and supports a backing plate of soft magnetic material and the plurality of permanent magnetic poles supported thereon or therein face the conductive windings of the stator disk, such that magnetic flux paths from one permanent magnetic pole to an adjacent magnetic pole extend in a region intersected by conductive windings and into said annulus of soft magnetic material and back across said region to said adjacent permanent magnetic pole.

2. A disk shaped brushless direct current electric motor having a disk-shaped stator and a disk-shaped rotor mounted on a central shaft so that the rotor can be positioned close to and rotate in a plane parallel to that of the stator with a gap therebetween, a plurality of permanent magnetic poles supported on or in a surface of the disk-shaped rotor facing the stator,
said stator having a plurality of wound poles supported by said stator characterised in that the stator disk is formed of plastic and the rotor disk is formed of plastic, the plastic stator disk having an annular cavity on a first face retaining an annulus formed from one or more portions of soft magnetic material which is electrically discontinuous, the plastic stator disk having on a second face a plurality of radial fingers supporting conductive windings,
the plastic rotor disk contains and supports a backing plate of soft magnetic material and has an annular ring magnet supported on and attached to said backing plate so that the ring magnet faces that portion of the stator having the conductive windings, the annular ring magnet having from 4 to 64 permanent magnetic poles magnetized in zones around the annular ring magnet,

such that magnetic flux paths from one permanent magnetic pole to an adjacent permanent magnetic pole extends in a region intersected by conductive windings and into said annulus of soft magnetic material and back across said region to said adjacent permanent magnetic pole, whereby a majority of said conductive windings intersect substantially all of the magnetic flux paths substantially at right angles.

3. A disk shaped brushless direct current electric motor as claimed in claim 1 or claim 2, characterised in that said annulus of soft magnetic material is formed from one or more portions of steel tape electrically insulated from one another.

4. A disk shaped brushless direct current electric motor as claimed in claim 3, characterised in that there are about 8 permanent magnetic poles on said rotor.

5. A disk shaped brushless direct current electric motor as claimed in claim 4, characterised in that said annulus of soft magnetic material comprises thin lamination steel tape and is wound in the form of an annular spiral.

6. A disk shaped brushless direct current electric motor as claimed in claim 5, characterised in that a cover plate is positioned over said annular cavity to contain said annular spiral.

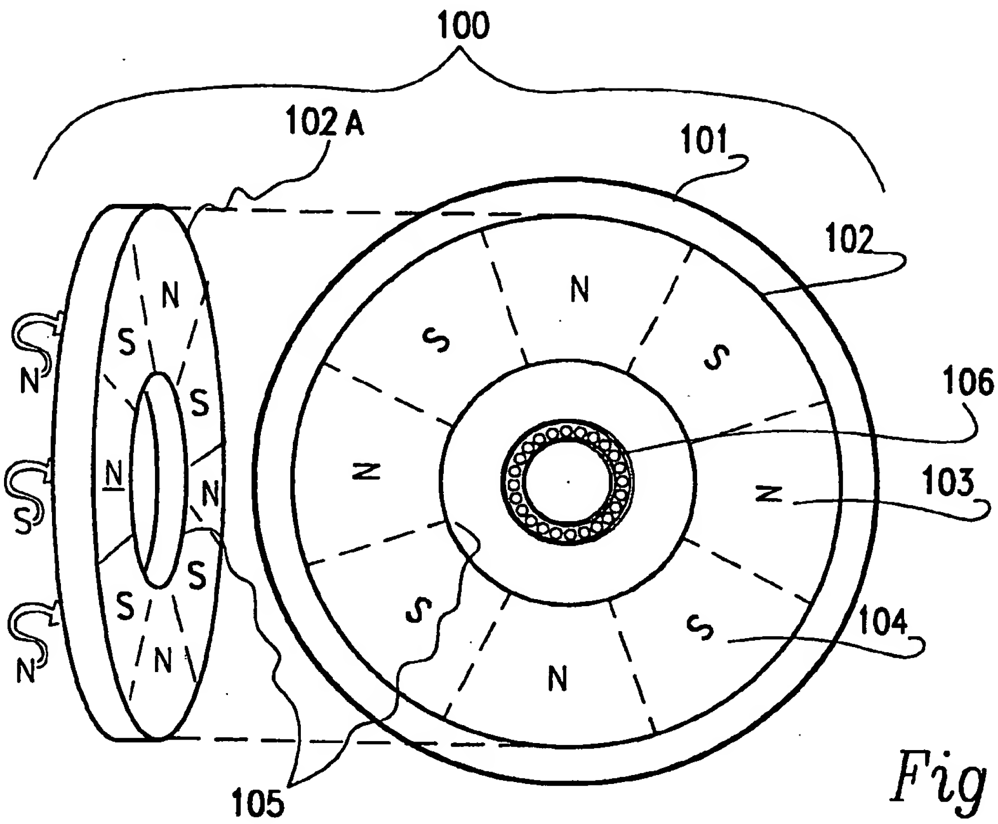
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Fig 1

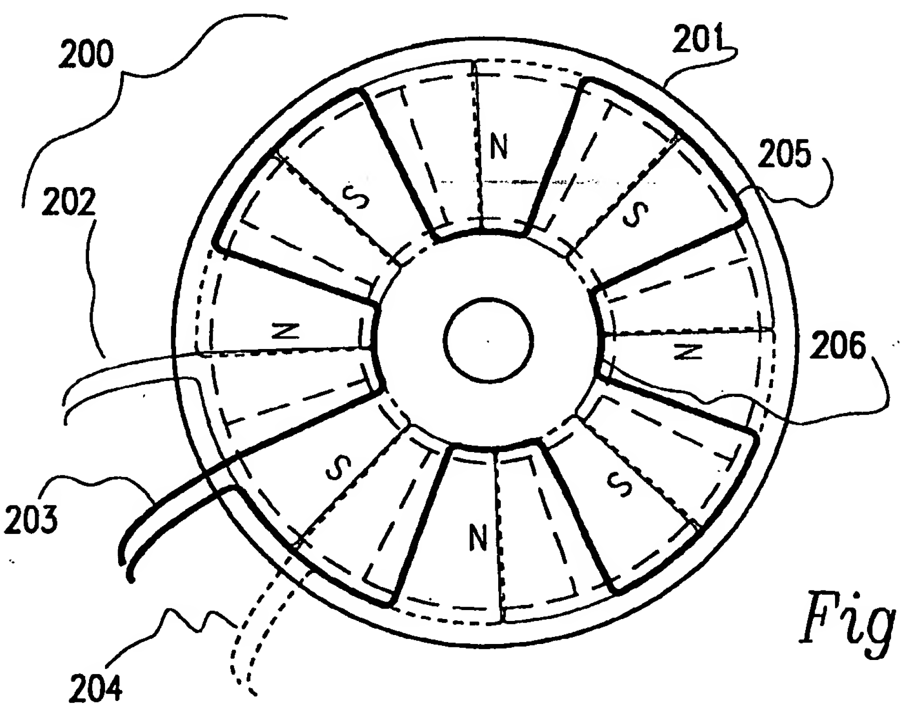
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Fig 2

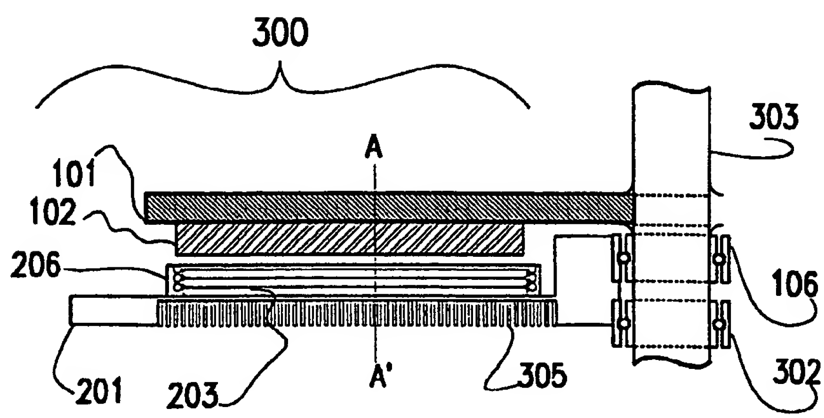

Fig 3

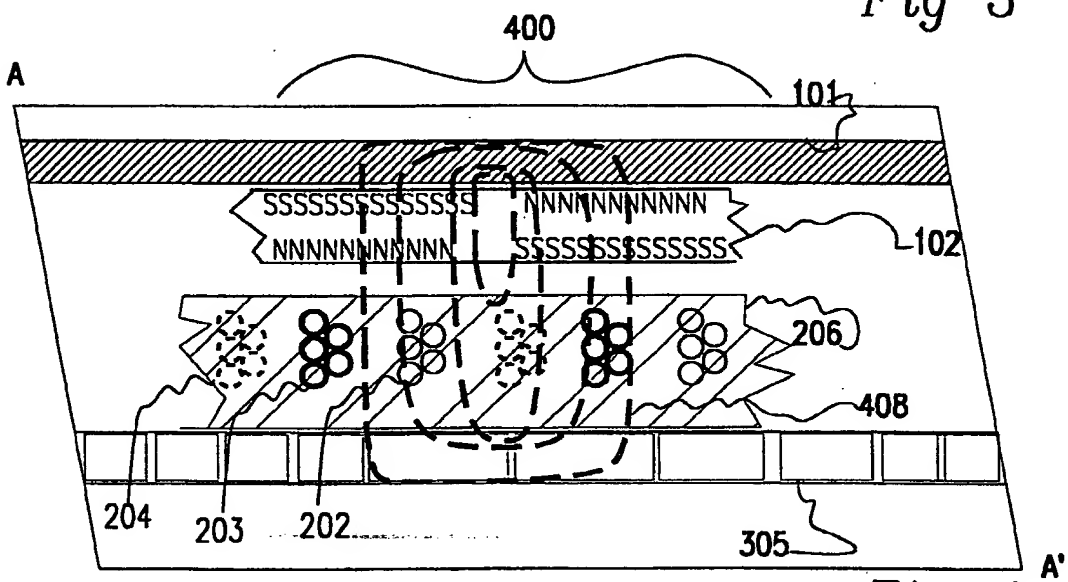

Fig 4

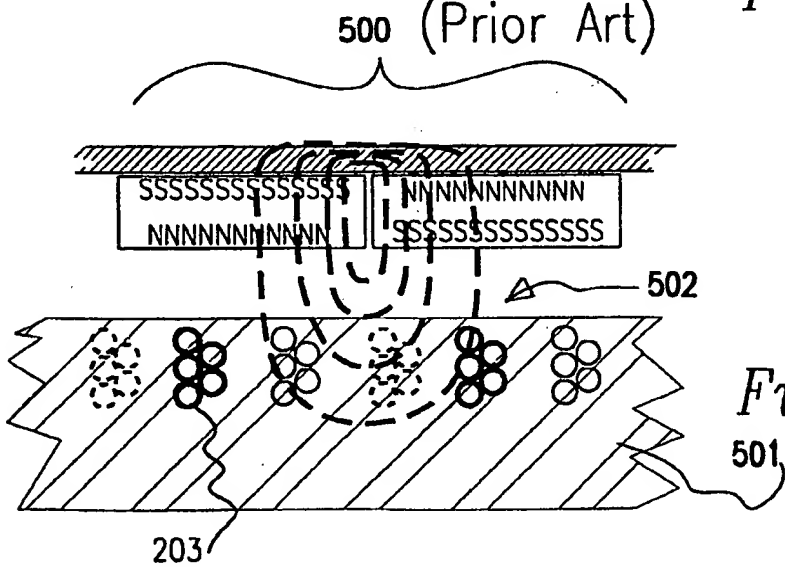

Fig 5

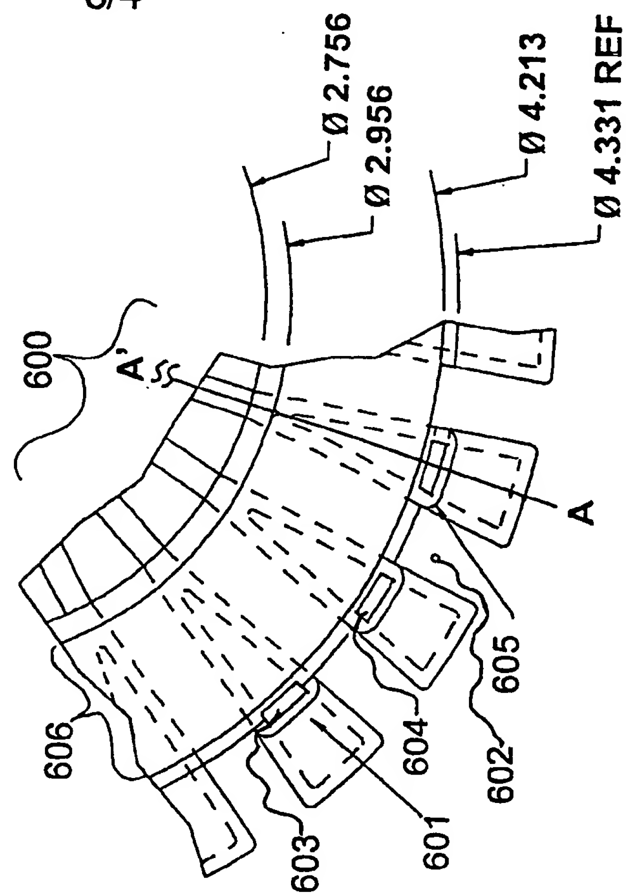
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Fig 6

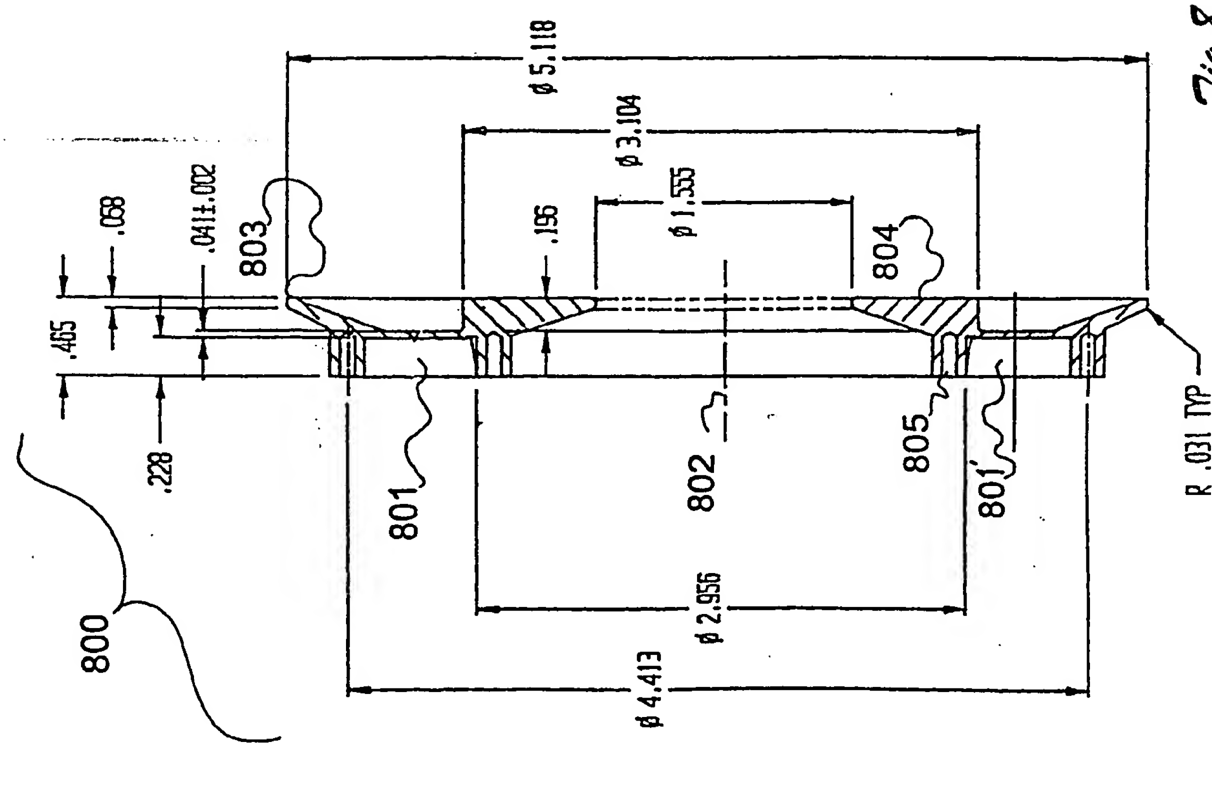
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Fig 8

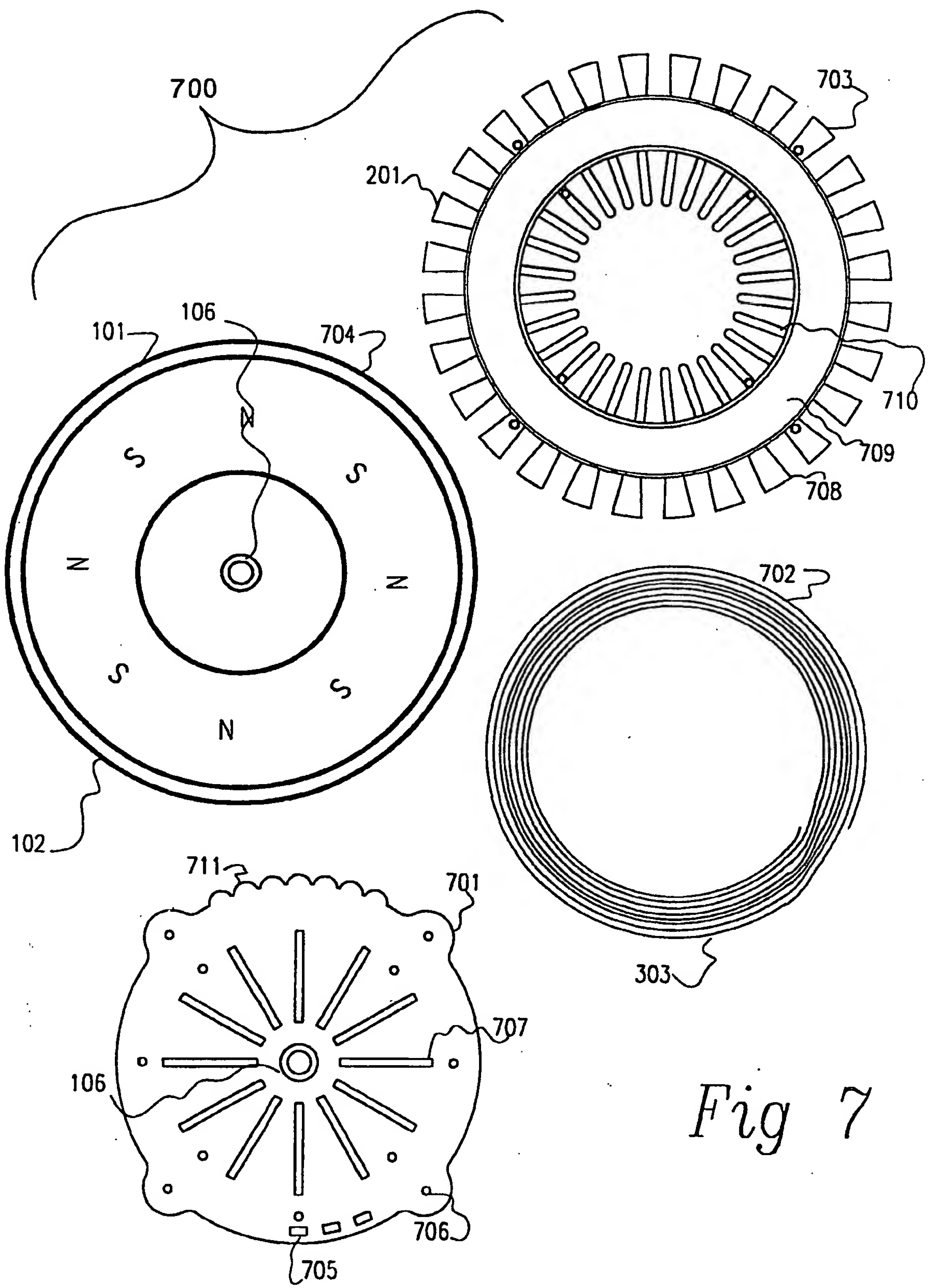
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Fig 7

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/NZ 96/00089

A.	CLASSIFICATION OF SUBJECT MATTER

Int Cl[6]: H02K 1/06, 1/27, 29/00

According to International Patent Classification (IPC) or to both national classification and IPC

B.	FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC : H02K 1/06, 1/27, 21/24, 23/54, 27/26, 29/00, 29/06, 37/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU : IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DERWENT :
JAPIO :

C.	DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 94/19859 A (CADAC LTD) 1 September 1994 see whole document	1-6
X	US 4633149 A (WELTERLIN) 30 December 1986 see description with reference to figures 1-4	1-6
X	AU 43451/85 (585863) B (MAGHEMITE INC.) 19 December 1985 see whole document	1

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 November 1996	22 Nov 1996
Name and mailing address of the ISA/AU AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No.: (06) 285 3929	Authorized officer E.N. PERRIS Telephone No.: (06) 283 2167

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/NZ 96/00089

C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4836631 A (SHIMAZU et al) 6 June 1989 see whole document	1
X	DE 3736033 A (PAPST-MOTOREN GmbH & CO) 28 April 1988 see description with reference to figure 5	1
X	GB 2202387 A (SONY CORP) 21 September 1988 see whole document	1
Y	US 4167692 A (SEKIYA et al) 11 September 1979 see col. 3 line 57 to col. 4 line 14 and figures 4-6	1, 2

INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application N .
PCT/NZ 96/00089

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9419859	AU	59806/94	CA	2147653		
US	4633149						
AU	43451/85	CA	1224235	BR	8502803	IN	164755
		MX	159372	EP	164827	GB	8414953
		US	4605874	US	4710667	ZA	8504381
US	4836631	KR	9203565	CN	86105102		
DE	3736033	CH	671855	DE	8714191		
GB	2202387	CA	1288461	CN	8810318	DE	3808222
		FR	2612701	JP	63224654	KR	9606137
		US	4851731				
US	4167692	AT	7785/77	CA	1094626	DE	2748543
		FR	2369728	GB	1576956	JP	53055724
		JP	53080508				

END OF ANNEX